LESSON 32 – ELECTRONICALLY STEERED ARRAYS
To this point, we've assumed that our radar antenna was a simple parabolic dish that was mechanically pointed at our intended target. This lesson will explain how modern radars don't really have to move at all.

Reading:
       Stimson **Ch.37, Ch 38**
Problems/Questions:
       Work on Problem Set 4
Objectives:
       32-1   Understand the physical processes in a phased array.
       32-2   Understand how a phased-array antenna is steered electronically.
       32-3   Know the cost and benefits of the phased array design.

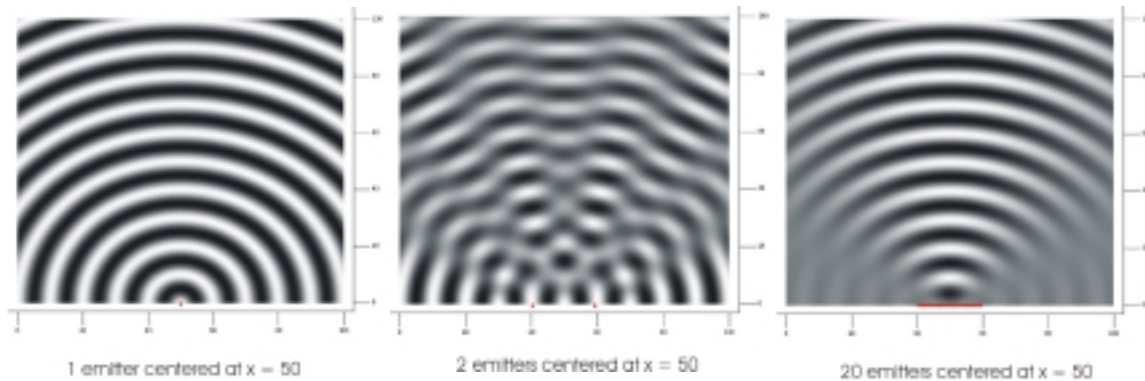Last Time: Doppler Ambiguities
             Clutter

Today: Phased Arrays
                    Interference
                    Beam Steering
                    Diffraction
                    Construction Techniques
                    Advantages/Limitations

Equations: $\Delta\phi = 2\pi\sin\theta_{steer}\,(d/\lambda)$
             $\theta_{3dB} = 0.88\,\lambda/(L\cos\theta_{steer})$

Motivation: the F-4's mechanically steered radar dish takes about a second to go from looking 60 degrees right to locking onto a target 60 degrees left. The F-22's electronically steered array (ESA) can do the same trick in under a microsecond.

Show slides from esa.mcd with 1, 2, and 10 emitters and $\Delta\phi = 0$. Discuss what the slide represents and review the concept of interference from physics 215 on the two source slide. Show single and double slit/laser demos. Show what happens when you add many more than 2 emitters.

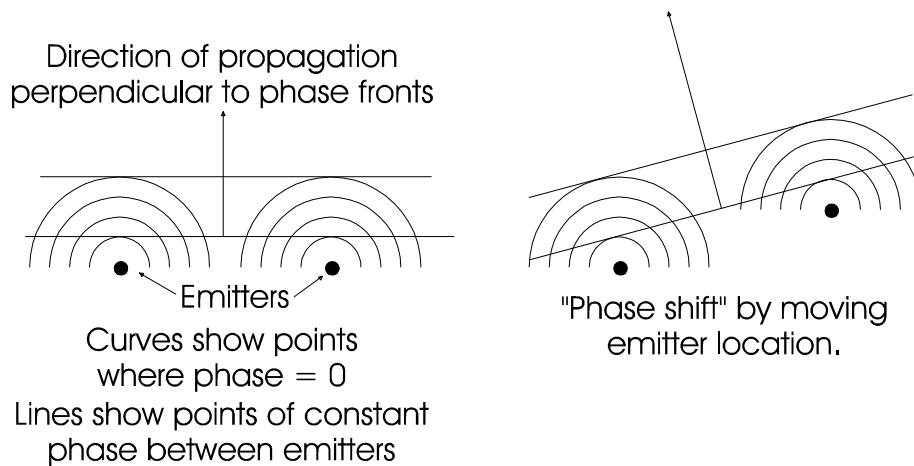1 emitter centered at x = 50   2 emitters centered at x = 50   20 emitters centered at x = 50

Show esa_emit.avi (shows effect of changing the number of emitters in the same array width). Emphasize that after a certain number of emitters, the beam shape doesn't change much because it becomes diffraction-limited.

Show esa_flex.avi (shows diffraction effects of same number of emitters with different interelement spacing).

Stimson talks about sidelobe reduction by tailoring the power profile across the array. Show esa_gaus.avi to illustrate this property.

So far, all we've done is discuss how a diffraction-limited beam can be produced by interference from many arrays. The real power of the electronically steerable array is its ability to change the direction of its beam very quickly. Let's see how this is accomplished.

Show Moiré pattern slides. Individually, each slide is a series of concentric circles. Together, there's an interference pattern. Put the two slides fairly close together so that only one "beam" is shown. On the board, show what in-phase and out-of-phase means with respect to phase fronts. Now, slide one of the Moiré patterns up a bit and demonstrate that the beam actually does change direction as the phase changes by drawing wave fronts over the slide on the board.
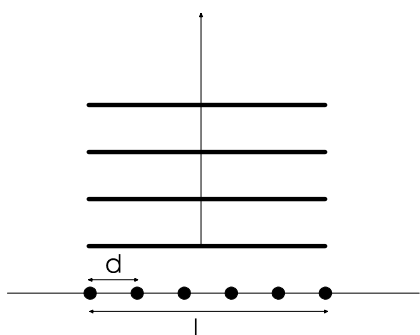
Direction of propagation
perpendicular to phase fronts

Emitters
Curves show points
where phase = 0
Lines show points of constant
phase between emitters

"Phase shift" by moving
emitter location.

Show esa.cdr series of slides, showing how a set of emitters that turn on at slightly different times is actually equivalent to a set of emitters that turn on simultaneously with slightly different phases. Show how the beam steering equation is derived from geometry to become $\Delta\phi = 2\pi\sin\theta_{steer}$ (d/λ). Stress that d is not the diameter nor the array length, but the interelement spacing

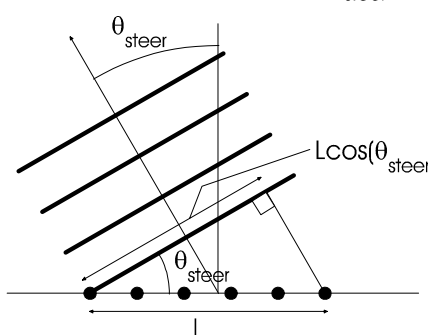Show esa_turn.avi to illustrate how phase shifts change the beam steering angle.

Show grating/laser demos and steer the beam. Note that the beam steers in the opposite direction that you turn the grating.

Show esa_turn.avi again. Show that the beamwidth gets larger as the beam is steered to the side. Look at the beam steering equation again and note the relationship d/λ that occurs in it. Where have you seen this relationship before? In diffraction! Let's look at diffraction for a linear array. The basic formula for this is $\theta_{3db} = 0.88\ \lambda/L$, where L is the width of the entire array. Show that if you steer the beam to the side, then L' is the new effective array length, and $L' = L\cos\theta_{steer}$. This means the real diffraction equation for an electronically steerable array is $\theta_{3dB} = 0.88\ \lambda/(L\cos\theta_{steer})$. This says that diffraction problems worsen as you steer further away from the normal.

Beam steering angle = 0

Beam steering angle = θ_{steer}

θ_{steer}

θ_{steer}

$Lcos(\theta_{steer})$

d

θ_{steer}

L

L

Discuss how real ESAs are constructed.

Advantages: RCS reduction (will be
discussed further in the stealth lesson); Beam
Agility; Reliability (designed to have 5-10%
T/R modules fail with no degradation to radar
operation); Weight Reduction (cooling
requirements reduced)

Disadvantages: Cost (computing
requirements); Diffraction problems;
Stabilization (for true ESA arrays with no
mechanical stabilization)

Show slide of actual ESA

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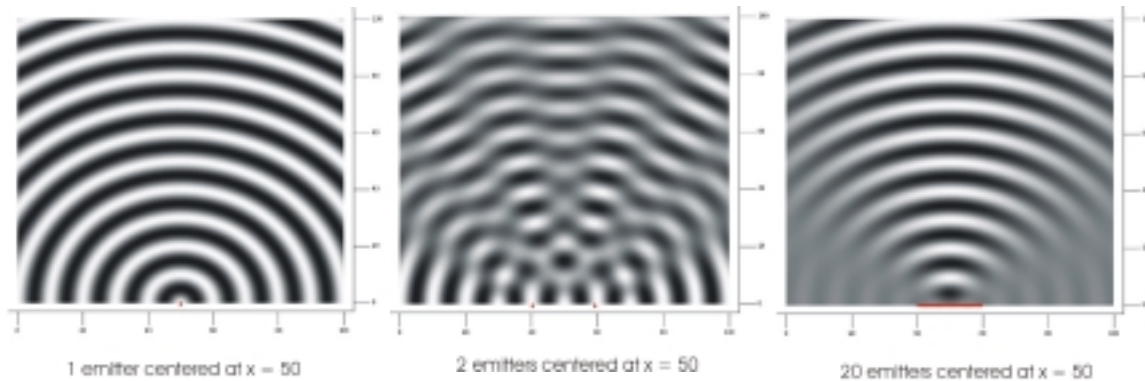Last Time: Doppler Ambiguities
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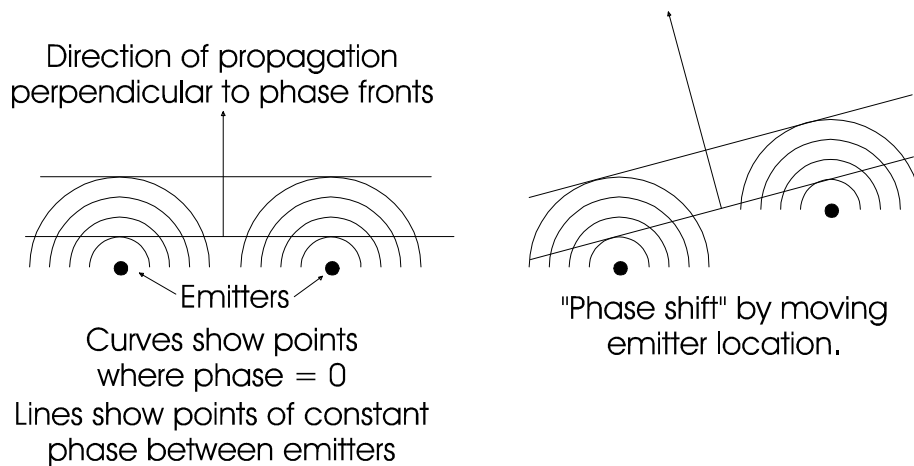1 emitter centered at x = 50   2 emitters centered at x = 50   20 emitters centered at x = 50

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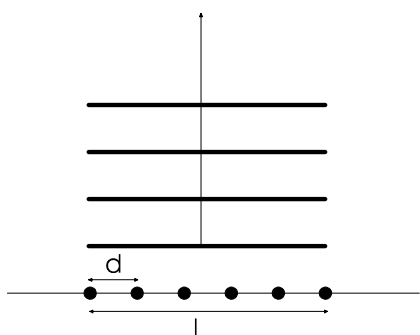
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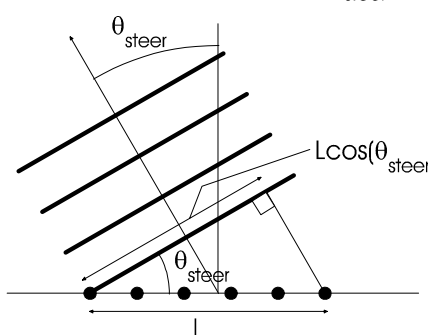Show esa_turn.avi to illustrate how phase shifts change the beam steering angle.

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